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Industry 4.0 impacts on lean production systems

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Abstract

The fourth industrial revolution and its Industry 4.0 or connected industry technologies dominates the current discussion of production research. Digital developments like cyber-physical Systems are the key technologies for future and more agile production systems but a common understanding of the term Industry 4.0 is not established at this time. First generic implementation approaches present manifold technical solutions but miss an integrated consideration with existing Lean Production Systems. The actual impact of Industry 4.0 solutions is mostly not clearly specified and a method to evaluate is missing.

This paper introduces the Industry 4.0 in an environment of connectability in the Internet of Things and Services with the vision of a smart factory. The initial situation of industrial companies is characterized by Lean Production Systems and Lean Principles. For companies, Industry 4.0 offers an estimated benefit by stabilizing Lean processes with Industry 4.0 applications. To support the development process the presented Concept of an Industry 4.0 impact matrix on lean production systems gives a useable framework. The matrix considers elements of lean production systems with Industry 4.0 technologies and gives a first estimation of impact. In the described development process of a cyber-physical Just-in-Time delivery the matrix is used to find a stabilizing application for a Just-in-Time material supply process.

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Keywords: cyber physical production system; connected industry; Industry 4.0; cyber physical system, Lean Production, technology management

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1. Industry 4.0 and existing lean production systems

According to the Gartner Hype Cycle for Emerging Technologies the key technology trends over the next ten years are immersive experiences, smart machines and platform revolutions [1]. Also within scientific research the quantity of publications on IT- and communication technology has raised rapidly. The term 'Industry 4.0' was formed in by the National Academy of Science and Engineering (acatech) and its working group founded on the Hanover exhibition in the year 2011 [2].

Meanwhile Industry 4.0 is an international accepted area of research in the field of Internet of Things (IoT). Based on the definition of the Cluster of European Research Projects on the Internet of Things (CERP-IoT) Industry 4.0 can be defined as the industrial vision to enable "people and things to be connected Anytime, Anyplace, with Anything and Anyone, ideally using Any path/network and Any service" [3].

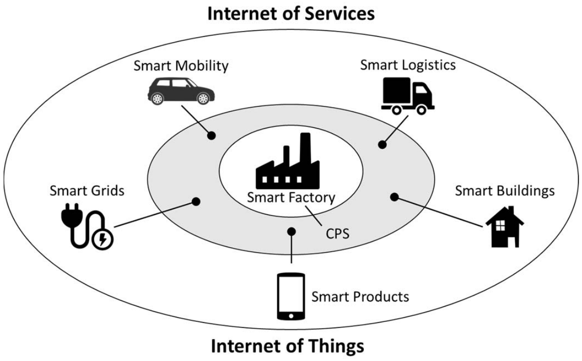

Fig. 1. Internet of Things and Services [2]

Smart factories are the central object of Industry 4.0. This concept figures out the usage of modern and further IT- and communication technologies to enable human beings, machines, products and resources to exchange information with each other. As shown in Figure 1 Industry 4.0 and its smart factories are part of a global Internet of Things and Services which is also the frame for visions with less industrial production relation like smart grids [2]. Following the vision of Industry 4.0 the industrial production will move from a physical process with IT support to an integrated cyber-physical system of production [2]. This cyber-physical systems combine the physical world with the cyber world by embedded computer controlled feedback loops [4]. From the technical perspective this means a total integration and connection of data acquiring sensors and data based controlling actuators.

For a successful implementation of Industry 4.0 the initial situation of industrial companies should be considered in a socio-technical view. The recent decades of western industrial production were characterized by the wave of lean production and lean management [5]. From this perspective an implementation of Industry 4.0 means also an integration of new technologies into existing lean production systems and an adjustment of business processes.

Following this consideration this paper focused on industrial companies with widely integrated lean production systems. The concept behind lean production is to avoid waste of non-value adding activities but also to keep processes and equipment simple and easy to use as well as easy to maintain. The approach of implementing complex IT solutions to connect machines, human and processes creates an unsolved dilemma between lean production and Industry 4.0. Nevertheless this paper presents a conceptual framework to find lean production supporting Industry 4.0 technologies. As shown in an industrial use case Industry 4.0 can achieve potentials to increase transparency and stability of lean principle following processes.

2. Concept and principles of lean production systems

2.1. System elements of production systems

Production is defined as fabrication and assembly as well as all functions and activities directly contributing to the making of goods [6]. The term production system describes the complex interrelation of technical functions and human functions as well as technical components and human components as a socio-technical system [7]. This system oriented management approach is based on the systems theory and the theory of cybernetics [8]. The socio-technical system considers interdependent human, technical, social and organizational subsystems connected via open interactions with their environment [9].

2.2. Lean Production System

The Toyota Production System (TPS) and its synonym Lean Production was developed by Toyota Motor Corporation in the 1970s. The TPS integrates a set of methods and tools with the management philosophy to completely eliminate the seven forms of waste (Muda) and to produce profit through cost reduction [10]. The TPS defines everything that does not create value as waste including: overproduction, waiting for work, conveyance, extra or wrong work, inventory, motion and correction of mistakes [11].

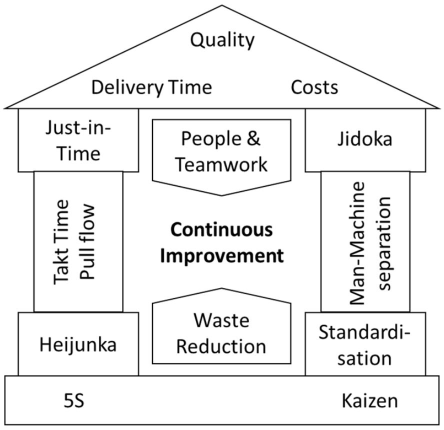

Fig. 2. House of Toyota Production System [12, 13]

The shown House of Lean Production (Fig. 2) is the symbol for the Lean Production principles. The triangle roof emblematizes the systematic focus on the customer oriented key performance indicators (KPI) for quality, delivery time and costs [12, 13]. The basic approach is a continuous improvement of production by an integration of the following principles:

- 5S,
- Kaizen,
- Just-in-Time (JIT),
- Jidoka,
- Heijunka,
- Standardisation,
- Takt time,
- Pull flow,
- Man-machine separation,
- People and teamwork and
- Waste reduction [14].

On this point the techniques to eliminate waste are named but to reach excellence the Lean philosophy has to be integrated in the business culture by leadership and coaching to improve processes every day [15].

Starting from this Japanese management philosophy western companies began to develop their own production system and several implementation approaches [16, 17, 18].

The rate of successful Lean Production implementation varied depending on the company size. Nowadays most industrial company groups are following Lean principles in comparison to that the implementation rate is low in small and medium sized companies [19, 20, 21].

3. Industry 4.0 technologies

3.1. Structuring of Industry 4.0 technologies

Industry 4.0 consists out of technological opportunities but also out of aspects of a management vision. The Industry 4.0 vision describes previously outlined implementation of a smart factory with necessary adjustments of management strategies, investigations into new business models as well as the development of new business processes. [22]

To identify lean production supporting industry 4.0 technologies, the focus of this paper will be set on the technical perspectives of cyber-physical systems (CPS) integrated into an industrial environment.

A quantitative analysis of publication databases puts the investigations around Industry 4.0 into an international context. China, USA, Germany, United Kingdom and South Korea dominating research on Industry 4.0 technologies. Between this countries a variation of intensity of research on different technologies can be identified [23].

The main key technology for Industry 4.0 are cyber-physical systems (CPS). CPS are the result of a closed loop of sensor based physical process data acquisition combined with software based (cyber) data processing and autonomous actuator based process controlling connected with the Internet and its data and services [24].

The application of CPS in a smart factory is called cyber-physical production system (CPPS). Based on the elements connected data acquisition, data processing, machine to machine communication and human-machine interaction a decentral autonomous production controlling will be possible [22].

To bring Industry 4.0 technologies into a structure based on CPPS elements they can be clustered into the following structure:

- Data acquisition and data processing
- Machine to machine communication (M2M) and
- Human-machine interaction (HMI) [22].

3.2. Data acquisition and data processing

Data acquisition and data processing are the enabler of CPS. Technologies of this cluster merge hardware based *sensors and actuators* to interact with the physical world. An additional middleware enables services like *cloud computing*. [25] For that reason so called smart objects are equipped with microelectronic, sensors, communication and processing modules. As result products, resources, machines and equipment get a form of basic intelligence. The Internet of Things and Services creates the environment to connect such smart objects with the global internet. [22]

All acquired sensor based process data will be stored in *big data* platforms as data base for *analytic* applications [25]. Analytic applications depending directly on sensor and actuator generated data of smart devices and smart machines [26]. This data enables the research on a huge amount of statistic process data directly out of the machines to identify instable process parameters or avoid quality issues inside defined tolerance

	Data Acquisition and Data Processing				Machine to Machine Communication (M2M)		Human-Machine Interaction (HMI)	
	Sensors and Actuators	Cloud Computing	Big Data	Analytics	Vertical integration	Horizontal integration	Virtual Reality	Augmented Reality
5S	+	+	+	+	+	+	++	+++
Kaizen	+	++	+++	+++	+++	+++	+++	+++
Just-in-Time	++	++	+++	+++	+++	++	+	++
Jidoka	+	+++	+++	+++	++	++	+	+
Heijunka	++	++	+++	+++	+++	++	++	+
Standardisation	++	+++	+++	+++	++	++	+++	+++
Takt time	+	+	+++	+++	+++	+++	+	+
Pull flow	++	+	+	+	+++	+++	+	+
Man-machine separation	+	+	+	+	+	+	+++	+++
People and teamwork	+	+	+	+	+	+	+++	+++
Waste reduction	+	+	++	+++	+++	+++	+	+

Fig. 3. Industry 4.0 impact matrix on lean production systems

ranges. A predictive maintenance is one possible result of this application. Based on big data an evaluation of business strategies is possible. Traditional key performance indicator (KPI) trees are used to manage, control and measure business performance on different levels. The collection and calculation of the values causes a huge effort in the traditional way. In the future this effort can be reduced by automatic calculations of big data applications. [27].

3.3. Machine to machine communication (M2M)

One of the main aspects of the vision Industry 4.0 is the machine to machine communication (M2M) based on CPS. The concept behind is to enable intelligent applications like auto-adaptive controlling of interconnected machines and equipment without human interaction [Chen 2012]. The M2M concept combines the approach of vertical and horizontal integration. The vertical integration connects machines and data on different levels. This means for example a gapless data connection of machine processes with manufacturing executive (MES) and enterprise resource systems (ERP). Data from ERP-system contain information about the production process parameters of every single product. A gapless vertical integration enables an individual one-piece-flow without manual change overs. [22] The approach of horizontal integration specifies the global communication between machines on the same level. In the case of a capacity constraint in production the connected machines can find available capacities in the network. Based on this information the production process can be changed autonomous according to an auto-adaptive production plan. [28]

3.4. Human-machine interaction (HMI)

The approach of industrial human- machine interaction (HMI) bases on the information sharing and collaboration between production machines and employees by interfaces like *virtual reality* or *augmented reality*. HMI solutions like data glasses are more or less in a state of research and development for industrial application. [Wittenberg 2016]

In general all these HMI are basing on sensor based live data on processes level [26]. An example for a human-machine interacting system is the approach of the robot assisted disassembly for recycling of electric vehicle batteries [29]. This concept shows a solution to cover the high amount of verifying vehicle battery models in disassembly in a collaboration based on optical sensor technologies combined with the possibility of additional manual post-treatment.

4. Concept of an Industry 4.0 impact matrix on lean production systems

The vision of Industry 4.0 and lean production meet each other in industrial companies. In the currently state of research the impacts of Industry 4.0 solutions on existing lean production systems are not specified. A framework which combines the principles, methods and tools of lean production and the upcoming IT-technology driven Industry 4.0 is missing [30].

To join both disciplines an ongoing investigation of first successfully implemented Industry 4.0 projects was started in cooperation with a global automotive company. The target of the project is to work out a decision supporting framework to identify potential Industry 4.0 solutions in the environment of a lean production system.

In the first phase of this project was dealing with possible impacts of Industry 4.0 technologies on existing lean production systems. First of all based on a research on lean production concrete lean principles were identified and analyzed. The identified lean principles (shown in 2.2) are listed in the left column of the Industry 4.0 impact matrix on lean production systems as shown in Figure 3. In the second step the investigation on Industry 4.0 was started with the target to analyze the structure of Industry 4.0 technologies. In this process identified technologies were analyzed and ordered in the structuring clusters (shown in 3.1). The clusters of Industry 4.0 give the first row followed by the allocated technologies in the second row. Finally the resulting framework of an Industry 4.0 impact matrix on lean production has to be filled out.

By the reason that most Industry 4.0 projects are not successfully implemented now, the current state of this matrix shows estimated values generated in a moderated workshop with 24 Industry 4.0 project leaders from the cooperating automotive company. Eight members of this workshop were lean production experts too and add their viewpoint of both disciplines.

In that workshop the technologies were rated by the estimated impact on the named lean production principles. The valuation code "+" means that there can be a low positive impact of this Industry 4.0 technology on this lean principle. Two rates "++" shows a high estimated impact and three rates "+++" stand for the highest possible impact from the technology on the corresponding lean production principle. To face the fast development in this field the matrix should be understand as a conceptual framework and is open to add upcoming technologies.

This shown Industry 4.0 impact matrix on lean production systems will support the development decision for Industry 4.0 solutions in an early phase. Existing processes can be analyzed for supporting Industry 4.0 technologies based on the estimated impacts as shown in the following use case.

5. Use case: Cyber-physical Just-in-Time delivery

5.1. Developing process for a cyber-physical Just-in-Time delivery solution based on the Industry 4.0 impact matrix

The cyber-physical Just-in-Time delivery is an IT-system designed to support a lean Just-in-Time material flow process. The system is balancing the material stock based on live data and Industry 4.0 technologies.

The developing process of this solution started in an automotive company with an integrated lean production system on a high maturity level.

In the first step a review on internal lean production assessments shows a potential in the process stability of just-in-time delivery for electrical assembly parts. For that reason the process description of the implemented JIT process was analyzed as well as the real process in the production.

In the second step a theoretical research of JIT was done to extract the main aspects of this principle as a base for the further solution development.

The first known definition from OHNO in 1982 describes Just-in-Time as "the act of having the right parts at the right time and at the right amount" [31]. This principle aims to a material flow oriented to the customer needs. Later definitions focusing on JIT as a philosophy concluded with the goal of the reduction of waste in the entire production system with the principal aim of product quality [23]. In this context main parts of waste are safety stock, work in progress and overproduction. The system to reduce these kinds of waste is to let every supplier only produce what his customer needs in minimal batches. Small batch sizes enable the reduction of lead time. As result the required amount of safety stock will decline and the products will be produced according to the customer demands [14]. Kanban is the production scheduling process to control JIT between machines and work stations with so called Kanban cards [14]. This cards are circulating between every source and drain to communicate the concrete required quantity of components.

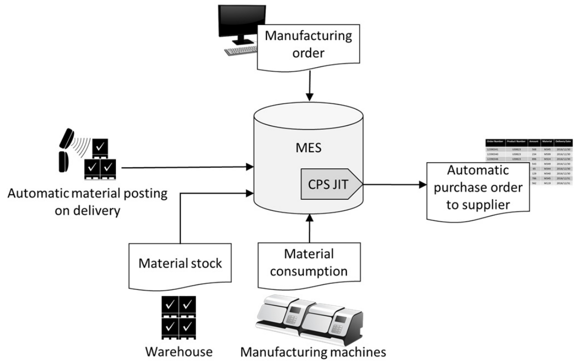

Fig. 4. Cyber-physical Just-in-Time delivery.

Within a third step the Industry 4.0 impact matrix on lean production systems was used to find technologies with a high positive impact on the JIT process. In the matrix the highest support is estimated by the integration of *big data*, *data analytics* and a *vertical integration of machine to machine communication*. The following development process was focusing on the implementation of this technologies as the fourth step of this procedure.

The starting point of the developed cyber-physical application was to replace the Kanban cards by a vertical integrated solution of machine to machine communication. The concept (Fig.4) was to create a gapless information flow between manufacturing order, material delivery, material stock and material consumption as well as an automatic purchase order to the supplier. On this point parts of horizontal integration were added. For the implementation a data base redesign on the manufacturing executive system (MES) was necessary. An additional JIT-service task was developed and integrated on a middleware system. The standardization of material ID-labels was also a challenge as the integration of the supplier into the automatic purchase process.

The material flow was changed by a direct delivery from the central warehouse to the machines without previous puffers on the shop floor. Every material movement gets detected by sensors and posted into a basic big data architecture. The required material gets resolved out of the manufacturing order and gets matched with the material stock in the warehouse.

Internal material logistic is implemented by a system based on Milkrun supply according to the material consumption.

If the material consumption of the manufacturing machines brings the material stock to the dynamic minimum inventory level an automatic purchase order will be sent to the supplier. Delivered material will be posted automatically by an optical RFID system and considered in the forecast of material requirements. The prognostic material requirement is calculated by an analytics service on statistical data in this data architecture. The analytics service compares the available information with a digital model of the complete process to decide on starting automatic purchase orders to the supplier.

An additional benefit was given by the increasing level of traceability and process reliability. The implemented cyber-physical Just-in-Time delivery enables a step by step elimination of shop floor near located stock and minimizes the warehouse space.

The implementation was started as the sixth step in reference lines and gets currently rolled out line by line in the business unit after a testing phase.

5.2. Assessment of Cyber-physical Just-In-Time delivery

For the evaluation of technical Industry 4.0 solutions the cyber-physical production system (CPPS) assessment gives a suitable framework. This method is based on the holistic approach of interacting physical components, virtual/digital components and employees [33]. According to this the assessment levels are defined as physical world, data acquisition, cyber world and feedback/Control [34] and covers the elements of Industry 4.0 technologies.

The *Physical World* of the cyber-physical Just-in-Time delivery system is represented by the physical material flow. Design and control actions are based on defined process parameters. The material flow and reorder is controlled by information about placed manufacturing orders, warehouse stock, calculated material consumption and posted material deliveries. According to the criteria of the CPPS assessment framework the highest rate is reached with level III.

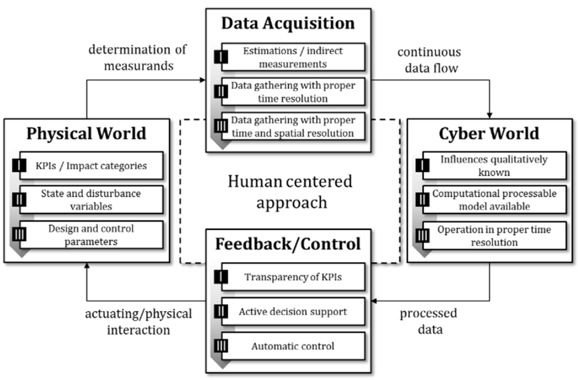

Fig. 5. CPPS assessment framework [34].

The measured data are in the focus of *Data Acquisition* assessment step. Measure points of material flow are gapless implemented along the physical material flow so that all required information of the system is available all the time. Data acquisition points are implemented on every input- or output point, for example on every machine. The sample rate of the overall system is limited by the Ethernet connection but fulfills the requirements of the use case. The necessary spatial resolution of data acquisition is given for the dynamics of the cyber-physical Just-in-Time delivery and achieves assessment level III.

The virtual process model of the system stands for the *cyber world*. The implemented model based on discrete events triggered by automatic material stock postings represents the complete material flow including the ordering process. The operating of the system occurs in a proper time for the given applications and fulfills the requirements for assessment level III.

The assessment level of the element feedback/control gets evaluated according to the conversion of processed data for interaction and human integration. In the cyber-physical Just-in-Time delivery application an automatic control of the material inventory is given including an automatic order process with regarded lead time and delivery times. The material flow and the automatic decisions are visualized and transparent for the employee in the connected business process system. Level III is achieved for this application.

Physical World	Data Acquisition	Cyber World	Feedback/ Control
Level III	Level III	Level III	Level III
Physical material flow is designed and controlled by parameters like manufacturing order, warehouse stock, material consumption and material delivery.	Data is achieved in the necessary spatial resolution and fulfills the required sampling rate of the application.	Operations are represented by a virtual model of the material flow including the material ordering process.	The process is controlled automatically and decisions are transparent for the employee.

Fig. 6. Assessment of cyber-physical Just-in-Time delivery.

The socio-technical views also focus also on the human in the system but is not a part of the CPPS assessment. The cyber-physical JIT delivery may affect the required human planning and thinking processes in the work system. A change from technology oriented tasks to process oriented perspective is published for similar work systems with implemented Industry 4.0 technologies and shows that the tasks require an increased comprehensive process overview and a higher rate of self-organization [35, 36]. Further impacts on work conditions, human learning and organizational knowledge management should be analyzed with methods like VERA/RHIA [35, 37, 38].

6. Conclusion and further investigations

New possibilities from information and communication technologies are matching with lean production environments. The paper shows that Industry 4.0 applications can stabilize and support lean principles. The Industry 4.0 impact matrix on lean production systems gives a framework to start design and develop Industry 4.0 integrated applications.

The use case of the cyber-physical Just-in-Time delivery application shows an assessable example for lean process improvements with Industry 4.0 technologies based on the presented impact matrix. In the next step the estimated impacts should be evaluated by statistic research and implemented in a design framework. Furthermore approaches to integrate sustainability into Lean Production Systems are available and should be extended by an integration of Industry 4.0 technologies. [39, 40]

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